



DEPARTMENT OF THE AIR FORCE
AIR FORCE CIVIL ENGINEER CENTER



14 Aug 17

MEMORANDUM FOR U.S. EPA Region IX
Attn: Ms. Carolyn d'Almeida
75 Hawthorne Street
San Francisco, CA 94105

Arizona Department of Environmental Quality
Attn: Mr. Wayne Miller, P.E., R.G
1110 West Washington Street, 4415B-1
Phoenix, Arizona 85007

FROM: AFCEC/ CIBW
706 Hangar Road
Rome, NY 13441

SUBJECT: Submission of "Response to EPA Memorandum (TechLaw) dated 24 March 2017, Review of the Groundwater Model, Final Remedial Design And Remedial Action Work Plan, May 2014, and Draft Final Remedial Design and Remedial Action Work Plan Addendum #2 for Operable Unit 2 Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona, March 2016"


and

"Response to ADEQ Comments dated 16 May 2017 on Site ST012 Contaminant Mass Estimation Process. LNAPL Volume Calcs; received March 23, 2017. An adobe.pdf of Amec Foster Wheeler (AMEC), Assorted Light Non-aqueous Phase Liquid (LNAPL) Volume Calculations; from various time intervals between 2015 and 2017"

1. The Air Force is pleased to submit the attached documents:

- a. *Response to EPA Memorandum (TechLaw) dated 24 March 201, Review of the Groundwater Model, Final Remedial Design And Remedial Action Work Plan, May 2014, and Draft Final Remedial Design and Remedial Action Work Plan Addendum #2 for Operable Unit 2 Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona, March 2016*
- b. *Response to ADEQ Comments dated 16 May 2017 on Site ST012 Contaminant Mass Estimation Process. LNAPL Volume Calcs.*

2. The Responses to Comments files are being issued under separate cover from the Revised Draft Final Addendum #2, Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012. Please contact me at (315) 356-0810 or by email at catherine.jerrard@us.af.mil if you have any questions regarding the responses to comments.



CATHERINE JERRARD, PE
BRAC Environmental Coordinator

Attachments:

1. Response to EPA Memorandum (TechLaw) dated 24 March 2017, Review of the Groundwater Model, Final Remedial Design And Remedial Action Work Plan, May 2014, and Draft Final Remedial Design and Remedial Action Work Plan Addendum #2 for Operable Unit 2 Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona, March 2016
 2. Response to ADEQ Comments dated 16 May 2017 on Site ST012 Contaminant Mass Estimation Process. LNAPL Volume Calcs; received March 23, 2017. An adobe.pdf of Amec Foster Wheeler (AMEC), Assorted Light Non-aqueous Phase Liquid (LNAPL) Volume Calculations; from various time intervals between 2015 and 2017
- c: ADEQ – Wayne Miller (2 and 2 CD)
 Administrative Record – AFCEC/CIBP-BRAC DR (1 CD)
 AFCEC – Catherine Jerrard (1 and 1 CD)
 SpecPro Services – Bill Hughes (1 and 1 CD)
 TechLaw – Nicole Goers (1 CD)
 USEPA – Carolyn d’Almeida (1 and 1 CD)
 USEPA – Eva Davis (1 and 1 CD)
 UXOPro – Steve Willis (1 CD)
 File



**RESPONSE TO EPA MEMORANDUM (TECHLAW) DATED 24 MARCH 2017
REVIEW OF THE GROUNDWATER MODEL
FINAL REMEDIAL DESIGN AND REMEDIAL ACTION WORKPLAN AND
DRAFT FINAL REMEDIAL DESIGN AND REMEDIAL ACTION WORK PLAN ADDENDUM #2
FOR OPERABLE UNIT 2
REVISED GROUNDWATER REMEDY, SITE ST012
FORMER WILLIAMS AFB, MESA, ARIZONA**

The objective of the groundwater modeling presented in the Remedial Design and Remedial Action Work Plan (RD/RAWP) was to demonstrate the capability of enhanced bioremediation (EBR) implementation; and in Addendum #2 to evaluate where groundwater should be extracted and injected to distribute terminal electron acceptor (TEA) to the target treatment zones. As such, the modeling is utilized as an engineering tool to guide design decisions with the expectation that actual site data collected during EBR may deviate from model assumptions and dictate adjustments in the EBR implementation. The Air Force's (AF's) intent is to use modeling as a tool to guide the initial EBR implementation based on reasonable assumptions but also acknowledges that actual progress during EBR implementation will be a more reliable indicator of the remedy's success. Significant changes in TEA injection locations and quantity are likely as site remediation progresses toward completion.

The U.S. Environmental Protection Agency (through TechLaw, Inc.) raises several technical concerns with the appropriateness of model input parameters and approaches. While the concerns often have valid scientific basis, the comments appear to focus on a different overall objective for the modeling. The primary objective of comments is to have a greater assurance (certainty) through modeling that the EBR remedy will be successful within the estimated remediation timeframe. Using sensitivity analysis to evaluate possible results based on ranges for multiple parameters will result in a wide range of outcomes, some of which are likely not representative of actual site outcomes. This approach can hinder decision making based on the lack of clarity associated with considering multiple combinations of input parameters. Sensitivity analysis may be utilized as a component of future modeling (subject to observed site data) to focus on identifying the significance of model parameters to model outputs, leading to evaluation of needs for collection of further site data. Sensitivity analysis will not be performed for parameters where the significance is already well established based on experience. This approach would provide to target which model parameters to further investigate and refine based on remedy progress. Future modeling and/or sensitivity analysis will provide results based on best available parameter estimates and prioritize potential parameters for further evaluation.

The modeling as performed in the RD/RAWP was used to demonstrate the appropriateness of EBR implementation and define the expected remedy timeframe. From the AF's perspective, additional effort spent refining the model and exploring parameter sensitivity is less valuable compared to generating site-specific data via EBR that can be used as verification of existing model parameters. Specifically, EBR implementation as the next step of the approved remedy will provide data to refine

biodegradation rates and the impact of remaining light non-aqueous phase liquid (LNAPL) on meeting the remedial goals. Calculations have been completed to develop reasonable estimates of remaining mass; however, such estimates are limited by the density of available data. Due to heterogeneity of mass distribution and limitations in the methods of quantification, it is not practical or possible to collect data in sufficient density to eliminate this limitation, so uncertainty regarding the contaminant mass will remain. The potential significance of this uncertainty limits the value of investing significant effort in the continued analysis of other model parameters and reactive-transport evaluations. Instead, project success is best achieved through initiating EBR implementation, monitoring its progress and continuing to use the model to support remedy evaluation with site data generated during implementation.

This philosophy as it relates to the modeling objectives as an engineering tool discussed above guides the AF responses to requested evaluation of input parameters and sensitivity analysis.

General Comments

1. The assumptions about mass transfer that were made for the Williams Groundwater Model are not consistent with recent research on mass transfer from light nonaqueous phase liquid (LNAPL) to groundwater. Mass transfer of constituents from LNAPL to groundwater at the ST012 site has been demonstrated to be rate-limited based on a detailed field mass transfer test (MTT) and related model evaluation of the data (Mobile et al., 2016; Kavanaugh et al., 2011). These findings are consistent with extensive research on NAPL dissolution rates that has been conducted over the past few decades (e.g., Miller et al., 1990). Mobile et al. (2016) also suggest that LNAPL dissolution rates will likely decrease with time as more LNAPL is removed and residual saturation (and related LNAPL globule and ganglia surface areas) decreases. The initial MTT was conducted immediately prior to the introduction of steam to the thermal enhanced extraction (TEE) test cell (Kavanaugh et al., 2011). However, the Groundwater Model assumes equilibrium conditions exist between LNAPL and aqueous-phase benzene, toluene, ethylbenzene, xylenes, and naphthalene (BTEX-N) constituents (i.e., unlimited mass transfer, resulting in effective solubility concentration levels in LNAPL areas). The Groundwater Model uses the MODFLOW SURFACT software; this equilibrium assumption is used to develop the governing transport equations and numerical solution techniques that form the basis of MODFLOW SURFACT [e.g., Section 2.2.3 (governing transport equations with residual NAPL) of the MODFLOW SURFACT User's Manual; HydroGeoLogic, 1996]. For example, SEAM3D modeling of the MTT indicates that under the observed rate-limited conditions, benzene concentrations in extraction-well effluent are likely to be as much as a factor of five or more times lower than equilibrium concentrations (Mobile et al., 2016; Figure 9). Therefore, the Groundwater Model may overestimate LNAPL dissolution rates by almost an order of magnitude and, depending on enhanced bioremediation (EBR) biodegradation rates (and whether the BTEX electron donor or the sulfate electron acceptor concentrations are limiting), may significantly underestimate remediation time frames. Please analyze the MTT results and evaluate the impacts of rate-limited LNAPL dissolution on the Groundwater Model predictions and the EBR system performance and design.

Response:

The AF has reviewed the MTT results presented in Mobile et al., 2016. This paper was not published at the time of the RD/RAWP modeling. One of the important differences between the MTT and the RD/RAWP modeling is the flow rates applied. The MTT used an injection flow rate of 35 gallons per minute (gpm) and a total extraction flow rate from five wells of 55 gpm for an approximate 17,000 square feet (ft²) area (~53 gpm per 10,000 ft²). For comparison, the RD/RAWP modeling had 55 gpm extraction and 45 gpm injection for a 140,000 ft² area (7 gpm per 10,000 ft²). Modeling in Addendum #2 used lower flow rates for similar areas and the approach includes periods of groundwater flow under non-pumping conditions. In the MTT injection and extraction flow rates were, “designed to enhance the possibility of observing induced nonequilibrium concentrations at monitoring wells located at more distant radii from the injection well.” As explained in the paper, sufficient induced pore velocities were required to generate observable decreases in benzene concentration relative to equilibrium. While Figure 9 in the paper shows that benzene concentrations in monitoring wells were reduced during the MTT, the test was designed to produce such reductions for the purpose of estimating the mass transfer coefficient. As discussed in the paper, at lower pore velocities the induced concentration is closer to equilibrium (e.g., Figure 3, 50 m³/d and 12 m radial distance). Given the lower pore velocities that result in a reduced influence of the non-aqueous phase liquid (NAPL) dissolution rate toward non-equilibrium concentrations in addition to the previously identified lack of accounting for enhancements of solubility by biosurfactant effects, the lack of rate limited dissolution does not significantly affect the use of the model for EBR design and implementation.

2. Groundwater Model soil-water partition coefficient input values should be corrected. The Groundwater Model was developed using BTEX-N soil-water partition coefficients, K_d , estimated from soil organic carbon measurements, f_{oc} ($K_d = k_{oc} f_{oc}$, where k_{oc} is the chemical-specific soil organic carbon-water partition coefficient; Lyman et al., 1982). K_d is a very important chemical transport parameter (comparable in importance to hydraulic conductivity) which is used to compute the chemical retardation factor, R_d , assuming linear equilibrium partitioning of mass between the soil (solid) and pore-water phases (Hemond and Fechner, 1994): $R_d = 1 + \frac{\rho_b K_d}{n_e}$. (ρ_b is the soil matrix bulk dry density and n_e is the effective soil porosity). For example, the chemical migration rate is directly proportional to hydraulic conductivity and inversely proportional to R_d . The total contaminant mass in an aquifer is also directly proportional to R_d , as well as aquifer cleanup times once the source is removed (e.g., Zheng et al., 1991). The $f_{oc} - k_{oc}$ relationship is valid for $f_{oc} > 0.001$ (Schwarzenbach and Westall, 1981; Hemond and Fechner, 1994, Section 3.5.1), but the Groundwater Model was based on $f_{oc} = 0.0003$. When the soil organic carbon content is low, research has shown that sorption sites other than organic carbon (e.g., adsorption of organic compounds to mineral surfaces) become increasingly important (Schwarzenbach and Westall, 1981). Due to these factors the $f_{oc} - k_{oc}$ studies indicate that f_{oc} should not be less than 0.001 when computing K_d (Schwarzenbach and Westall, 1981). Since the Groundwater Model used $f_{oc} = 0.0003$, the simulated BTEX-N advection, dispersion, and biodegradation rates could all be as much as a factor of three times too high, and the Groundwater Model may significantly underestimate remediation time frames depending on the relative

importance of aqueous- phase transport mechanisms (advection, dispersion, sorption, biodegradation) and LNAPL dissolution rates. Please correct the Groundwater Model soil-water partition coefficient input values and evaluate the impacts on the Groundwater Model predictions and the EBR system performance and design. Please also include in the modeling report the site-specific f_{oc} measurements from earlier investigations.

Response:

The mass of remaining contaminants at ST012 is dominated by the content in the NAPL phase so the proposed changes in f_{oc} will not have a large impact on the estimates of overall mass at the site. The site-specific f_{oc} measurements are based on the HGL, 2005 report referenced in Appendix M of the TEE Pilot Test Report (BEM, 2011). BEM also indicated that the sorption parameter, “had limited impact on calibration of the model to the steady-state benzene plume, so no sensitivity analysis was performed with respect to sorption parameters.” Although the basis for using a higher f_{oc} of 0.001 is sound, this change is unlikely to be as significant to the results as suggested. Future reactive-transport modeling will incorporate the higher f_{oc} value.

3. The sources [field measurements (e.g., from slug tests or pumping tests), model calibration, or assumption] of hydraulic conductivity (K) values for the Groundwater Model are not explained clearly in the modeling reports and the sensitivity of the EBR simulations and design to K was not evaluated. For example, the Final Remedial Design and Remedial Action Work Plan, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona, May 2014 (RD-RAWP) Appendix E modeling report states that the Cobble Zone (CZ) was “assigned” $K=70$ feet/day and that K of the Lower Saturated Zone (LSZ) was determined from some form of model calibration without specifying the details. However, in the Groundwater Model, K in the LSZ ranges from 10 to 12 feet/day, but the MTT measured order-of-magnitude higher depth-averaged LSZ K values of 80 to 300 feet/day (Mobile et al., 2016). The source of K values for the Upper Water Bearing Zone (UWBZ) was not clearly specified, other than stating that these K values came from earlier modeling work (e.g., BEM, 2010). Further, the Groundwater Model assumes that the vertical hydraulic conductivity, K_z , is a factor of ten lower than horizontal K, but no field measurements of K_z were made. The modeling report acknowledges that K_z is an important parameter for EBR system design (e.g., it affects vertical groundwater flow from the UWBZ to the CZ near UWBZ injection wells), and it is well-established (Hantush, 1964) that K_z is an important hydraulic parameter for designing partially-penetrating extraction/injection wells, such as those utilized in the EBR design. Please examine the sensitivity of the EBR system design (e.g., well spacing, flushing rates, and sulfate loadings) and simulated remediation times to reasonable variations in horizontal and vertical hydraulic conductivity values. Please ensure that the sensitivity and uncertainty analyses take into account the number of available K measurements for each hydrogeologic unit and discrepancies in LSZ K values suggested by the recently-published MTT results.

Response:

The CZ has only contained groundwater in recent years so historical testing for hydraulic conductivity is not available. The value of 70 feet per day (ft/day) was selected based on literature review for the types of soil present in this layer and model calibration to transient water level rise and gradients observed in the CZ. Hydraulic conductivity fields

in the UWBZ and the LSZ were originally developed for the TEE Pilot Test using measured values and parameter estimation tool (PEST) calibration (BEM, 2011). These values were used in the RD/RAWP model as indicated in RD/RAWP Appendix E which states, “these hydraulic conductivity fields were copied from Figures M.3.2.1 and M.3.2.2 in Appendix M of the TEE Pilot Test Report (BEM, 2010).”

As explained in the MTT paper, the LSZ was characterized for the MTT as consisting of two higher conductivity intervals (B and C) separated by a lower permeability interval with the B interval representing greater than 80 percent of the LSZ thickness. The MTT measured depth averaged K values of 80 feet/day in the B interval and 300 ft/day in the C interval. The K in the lower permeability layer was not specified and a depth average K over the entire LSZ is not indicated which would be required for an appropriate comparison of the K values from the MTT to the K values in the RD/RAWP modeling. The detail of the layers and associated K values is greater for the MTT than available for the larger LSZ contaminant extents evaluated in the RD/RAWP model and is not sufficient to justify different hydraulic conductivity values than were used in Appendix M of the TEE Pilot Test report, which included consideration of the same information presented in the MTT paper.

The model uses assumed vertical hydraulic conductivities 10 times lower than horizontal conductivities. Estimates of vertical hydraulic conductivity have been made based on historical laboratory measurements and are summarized in the Focused Feasibility Study (AMEC Environment and Infrastructure, Inc., 2012) which suggest ratios of horizontal to vertical hydraulic conductivity from 3.4:1 to 300:1. Vertical dispersivity also plays an important role in the distribution of sulfate and contaminants in the model and has been incorporated based on values determined in the field test. (see Appendix D of RD/RAWP Addendum 2, Amec Foster Wheeler Environment and Infrastructure, Inc., 2017)

Sensitivity analysis would be expected to show that the model is sensitive to changes in conductivity; however, the overall hydraulic conductivity fields for the UWBZ and LSZ were developed based on measured values at known locations. Expansion of the MTT values across the full model domain would not be supported by the site data.

4. The Groundwater Model reports indicate that the EBR design is based largely on groundwater flow and pathline modeling as opposed to chemical transport (advection-dispersion), sorption, and biodegradation modeling. Full-scale reactive transport modeling was only performed to estimate remediation time frames based on predicted benzene concentrations (e.g., Table E-4.14 in Appendix E of the RD-RAWP). The modeling reports present significant discussions of groundwater and sulfate “mixing” rates and times, but it is very difficult to independently evaluate these statements and calculations in relation to how the field-scale EBR system will actually perform or whether reactive transport modeling would yield similar results. Please use the reactive transport model to demonstrate the sensitivity of the EBR design (e.g., well spacing and pumping rates) and remediation time-frame estimates to all of the key Groundwater Model input parameters, including those discussed in this set of comments.

Response:

As explained in the introduction, the purpose of the modeling in Addendum #2 was focused on evaluating Phase 1 for distribution of sulfate. For this purpose, a full reactive-transport model is unnecessary. Because the Addendum #2 modeling encompasses the Phase 1 injections and the necessity and scope of subsequent injection(s) is unknown at this time, the reactive transport model will not be useful in Addendum #2. Comments on sensitivity analysis are addressed through the other general responses to comments within this set of comments.

5. Due to the Groundwater Model complexity, it is not possible to independently evaluate the predictive EBR simulations (e.g., 20-year benzene concentration predictions) because no model outputs are presented in the reports. The MODFLOW SURFACT code automatically writes output files containing the relevant simulation results, and figure generation (contour plots and x-y graphs) is straightforward using modern Graphical User Interfaces (GUIs) (e.g., Groundwater Vistas), but none of these were added to the reports. For this type of flow and transport simulation, the following standard output needs be included in the modeling report to enable independent analysis and review: horizontal and vertical groundwater (aqueous-phase) concentration contour plots (all constituents; BTEX-N and sulfate) for selected layers in each hydrogeologic unit and for several times during the simulation (including initial conditions); hydraulic head contour and velocity vector plots; LNAPL saturation contour plots for different layers and times; LNAPL constituent mole- or mass-fraction contour plots for different layers and times; and various time-dependent mass balance x-y graphs (total LNAPL volume/mass; various LNAPL constituent (e.g., BTEX-N) mass plots; total aqueous-phase mass for each constituent (BTEX-N and sulfate); total BTEX-N constituent mass sorbed to soil; and total mass (BTEX-N and sulfate) versus time into and out of the model for these sources and sinks: biodegradation (sink), BTEX-N dissolution from LNAPL, extraction/injection wells, inflow/outflow through model domain boundaries, and change in mass storage (aqueous- and sorbed-phases).

Response:

Additional outputs were not previously requested but can be provided in future modeling efforts. Most of the requested outputs are related to a reactive-transport model which do not apply to the Addendum #2 model for sulfate distribution. In Addendum #2, horizontal concentration plots for sulfate are provided for selected layers in the CZ, UWBZ, and LSZ. These are now supplemented with figures showing vertical distribution through a section. In addition, groundwater contour and velocity vector plots are also provided.

6. The Appendix E RD-RAWP modeling report does not provide justification for increasing the sulfate utilization rate. The following statements relative to biodegradation rates under sulfate-reducing conditions are made in Section 4.5.6 of the Appendix E modeling report in the RD-RAWP: *“For the purpose of this assessment; and, without in-situ tests to provide a sulfate utilization rate and/or a decrease in half saturation constants under sulfate amended conditions, the utilization rate of sulfate was increased 10 fold from that value shown in Table E-4.11 (emphasis added)”* and, *“It is assumed that sulfate reducing bacteria biomass in the presence of high concentrations of sulfate will experience exponential growth and this will increase the efficiency and utilization of sulfate for petroleum hydrocarbon biodegradation.”* The justifications for increasing the biodegradation rate for sulfate-reducing conditions by

such a large amount (10 times) do not appear to be very strong. It is unclear what evidence is available from site-specific EBR monitoring to support such a high biodegradation rate in the predictive modeling. Considering that it is very difficult to predict with high a high degree [sic] of confidence future, and spatially-varying biodegradation rates, *please examine in more detail the sensitivity of the EBR design and model predictions of future benzene concentrations to a reasonable range of biodegradation rates.*

Response:

In the Appendix E modeling report, the maximum utilization rates for benzene and other soluble NAPL constituents were increased 10 times to 0.00875 and 0.00625 day⁻¹, respectively. This increase was made for the CZ, UWBZ, and LPZ (i.e., from Table E-4.11) but not the LSZ. This increases the upper limit of utilization potentially allowing for the utilization rates to reach tenfold or ten times the maximum value used in the UWBZ model presented in the Appendix M of the TEE Pilot Test Report. As a point of comparison, the LSZ model in Appendix M of the TEE Pilot Test Report uses maximum sulfate utilization rates that are 20 times those used in the UWBZ model and double the values used for the CZ, UWBZ, and LSZ in the model presented in Appendix E of the RD/RAWP. Based on review of 16 published first-order decay coefficients for benzene decay via sulfate reduction, the median, mean, and maximum are 0.003, 0.008, and 0.049 day⁻¹ (Suarez, 1999). These rates are between approximately four times and 56 times the maximum utilization rate for benzene used in the UWBZ model presented in the Appendix M of the TEE Pilot Test Report. The values used in Appendix M of the TEE Pilot Test Report were representing natural (not sulfate enhanced) conditions. Using a maximum utilization rate that is 10 times the low value used in the UWBZ for enhanced sulfate biodegradation of petroleum hydrocarbons, even benzene, is conservative, which was the intent of the RD/RAWP model

7. The longitudinal dispersivity, a_L , value used in the Groundwater Model for the LSZ ($a_L = 10$ feet) is much larger than the a_L measured during the MTT (LSZ value of $a_L = 2$ feet; Mobile et al., 2016). Appendix C, Section 3.3, in the Draft Final Addendum #2, Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona, March 2016 (Addendum #2) recommends that future modeling use $a_L = 20$ feet based on the results of the EBR field push/pull test. Addendum #2 also recommends that future EBR transport modeling increase the horizontal and vertical transverse dispersivities by about a factor of ten. A critical review of dispersivity observations from 59 different field sites (Gelhar et al., 1992) indicates that the LSZ value of $a_L = 2$ feet would be more appropriate for a site of this scale. Since dispersion is an important mixing mechanism, *please examine the sensitivity of the EBR design and model predictions to the dispersivity parameters (longitudinal, transverse horizontal, and transverse vertical).*

Response:

The MTT paper was not available at the time the RD/RAWP modeling was completed. Dispersivity values were assumed for the RD/RAWP modeling and measurement of dispersivity was one of the goals of the EBR field test. The values estimated from the field test were used in the Addendum #2 modeling.

Detailed reviews of transport studies have shown that dispersivity is a scale-dependent parameter (Gelhar et al, 1992). These and many other studies have shown that as the size of a contaminant plume increases, the effective dispersivity increases. Considering the scale of ST012 and the scale of tests presented in Figure 1 in Gelhar et al, 1992, that are comparable (>20 meters and <200 meters), longitudinal dispersivity values at approximately 5 feet are in the mean range for porous media. In review of the MTT paper the dispersivity value was calibrated using the parameter estimation tool (PEST). Although initial values used in the PEST calibration were reported in the paper (Table 1) the other PEST inputs are not included (e.g., the upper limit), which may be limiting the PEST solution. Additionally, the MTT simulation contains a single zone conductivity within each layer while the model presented in Addendum #2 has a range of conductivity values. Also, the model presented in the MTT has a smaller domain and different boundary conditions compared with the model presented in Addendum #2. These factors are expected to result in different values for hydrodynamic dispersivity, which represents variability in hydraulic conductivity over the scale of the area being studied. Results from the push-pull test were used to estimate or refine the dispersivity values used in the model considering its specific architecture. Considering the purpose of the model presented in Addendum #2, which was to examine the distribution of sulfate from injection wells, a longitudinal dispersivity at 20 feet is conservative compared to lower dispersivities, which would limit the downgradient spreading.

8. Slow desorption of contaminants from the soil matrix and larger-scale aquifer heterogeneities has been well-established as an important field-scale mechanism that reduces the effectiveness of remediation systems (e.g., the “tailing effect” in pump-and treat effluent concentration reductions; Hadley and Newell, 2012, 2014; Siegel, 2014; Sudicky and Illman, 2011; Culver et al., 1997), but this was not considered in the Groundwater Model. Multi-rate desorption can also significantly impact effluent concentrations for extraction and monitoring wells (Cosler, 2004). Slow desorption of aqueous-phase constituents, in addition to rate-limited LNAPL dissolution, should also realistically be expected to have some level of impact on the EBR system performance (e.g., extend remediation time frames). The RD-RAWP modeling report frequently acknowledges the importance of heterogeneities but does not present any quantitative analyses of their potential effects. Please include analyses of the potential impacts of aquifer heterogeneities (e.g., hydraulic conductivity, soil-water partition coefficient, and biodegradation rate) on EBR performance.

Response:

Movement of petroleum hydrocarbons between phases including desorption and adsorption from dissolved and liquid to solid phases is simulated in the model using equilibrium partitioning coefficients like K_d . These coefficients are equilibrium ratios that redistribute contaminant mass into phases based on a linear relationship between the simulated or active-phase solution in the model and the remaining phases. The active phase used in the model is water; therefore, the solution for reactive transport (advection, dispersion, diffusion, biodegradation) is solved for the water-phase and then the total mass in the remaining phases (solid, liquid, and vapor) are redistributed via partitioning coefficients. The model includes large-scale and small-scale heterogeneities that include a three-dimensional architecture to define the vertical variation in the

generalized geology; variable horizontal hydraulic conductivity zones in the LSZ and UWBZ; anisotropy between the horizontal and vertical hydraulic conductivities; and, longitudinal, transverse, and vertical hydrodynamic dispersivity. Additionally, the larger-scale three-dimensional aspect of the model interaction between different geologic units (e.g., back diffusion from the LPZ to the UWBZ and LSZ) is simulated. These model heterogeneities are considered in the active-phase solution thereby influencing phase redistribution at the conclusion of each time step in the model.

Conducting sensitivity analysis to determine the possible range of outcomes can be performed; however, using the sensitivity to arrive at a worst case or near worst case outcome to assess the approach is not recommended. Focusing on a solution using the lower or upper-end probabilities would likely result in an approach that either greatly under- or overestimates remedial design criteria (e.g., well spacing, pumping rates, duration). Instead, the RD/RAWP and Addendum #2 models presented are deterministic and represent the best estimates for model parameters in order to assess expectations for the remedial action outcome (RD/RAWP model) and to assist in selecting remediation well locations and flow rates (Addendum #2 model). As such, the model is being used as a tool for remedial design. Future model sensitivity analyses may be used to assess the focus of remedial action monitoring, assessment, and modifications.

REFERENCES

- AMEC Environment and Infrastructure, Inc., 2012. *Final Focused Feasibility Study*, Remedial Alternatives for Operable Unit 2, Site ST012, Former Williams Air Force Base, Mesa, Arizona.
- Amec Foster Wheeler Environment and Infrastructure, Inc. (Amec Foster Wheeler), 2017. Revised Draft Final Addendum #2 Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona, August 8.
- Anderson, R.T and D.R. Lovley, 2000, Anaerobic Bioremediation of Benzene under Sulfate-Reducing Conditions in a Petroleum-Contaminated Aquifer, *Environ. Sci. Technol.* 2000, 34, 2261-2266
- BEM, 2011. Final Phase I Thermal Enhanced Extraction (TEE) *Pilot Test Performance Evaluation Report*.
- Cosler, D.J. 2004. Effects of Rate-Limited Mass Transfer on Water Sampling with Partially Penetrating Wells. *Ground Water*, Vol. 42, no. 2. pp. 203-222.
- Culver, T.B., S.P. Hallisey, D. Sahoo, J.J. Deitsch, and J.A. Smith. 1997. Modeling the Desorption of Organic Contaminants from Long-Term Contaminated Soil Using Distributed Mass Transfer Rates. *Environmental Science and Technology*, 31(6), 1581-1588.
- Gelhar, L.W., C. Welty, and K.R. Rehfeldt. 1992. A Critical Review of Data on Field-Scale Dispersion in Aquifers. *Water Resources Research*. Vol. 28, No. 7. pp. 1955-1974.
- Hadley, P.W., and C.J. Newell. 2012. Groundwater Remediation: The Next 30 Years. *Groundwater*, Vol. 50, No. 5. 669-678.
- Hadley, P.W., and C.J. Newell. 2014. The New Potential for Understanding Groundwater Contaminant Transport. *Groundwater*, Vol. 52, No. 2. 174-186.
- Hantush, M.S. 1964. Hydraulics of Wells. *Advances in Hydroscience*. Vol. 1. Academic Press. Ed. V.T. Chow. 282-437.
- HydroGeoLogic, Inc., 2005. Modeling Groundwater Flow and Benzene Transport at Site ST012 Former Williams Air Force Base, Arizona. December 2005.
- Hemond, H.F., and E.J. Fechner. 1994. *Chemical Fate and Transport in the Environment*. Academic Press.
- HydroGeoLogic, 1996. MODFLOW-SURFACT Software (version 3.0) Documentation, Volume II: Transport Modules.

- Kavanaugh, M.C., R. Deeb, J. Nyman, L. Stewart, and M. Widdowson. 2011. Improved Field Evaluation of NAPL Dissolution and Source Longevity. ESTCP, Arlington, VA.
- Lyman, W.J., W.F. Reehl, and D.H. Rosenblatt. 1982. *Handbook of Chemical Property Estimation Methods*. McGraw-Hill Book Company.
- Miller, C.T., M.M. Poirier-McNeill, and A.S. Mayer. 1990 Dissolution of Trapped Nonaqueous Phase Liquids: Mass-Transfer Characteristics. *Water Resources Research*, 26(11), pp. 2783-2796.
- Mobile, M., M. Widdowson, L. Stewart, J. Nyman, R. Deeb, M. Kavanaugh, J. Mercer, and D. Gallagher. 2016. In-Situ Determination of Field-Scale NAPL Mass Transfer Coefficients: Performance, Simulation and Analysis. *Journal of Contaminant Hydrology*, 187, pp. 31-46.
- Siegel, D.I. 2014. On the Effectiveness of Remediating Groundwater Contamination: Waiting for the *Black Swan*. *Groundwater*, Vol. 52, No. 4. 488-490.
- Schwarzenbach, R.P., and J. Westall. 1981. Transport of Nonpolar Organic Compounds from Surface Water to Groundwater. Laboratory Sorption Studies. *Environmental Science & Technology*, 15(11), pp. 1360-1367.
- Suarez, M.P and H.S. Rifai, 1999, *Bioremediation Journal* 3(4):337-362, October 1999.
- Sudicky, E.A., and W.A. Illman. 2011. Lessons Learned from a Suite of CFB Borden Experiments. *Groundwater*, Vol. 49, No. 5. 630-648.
- Zheng, C., G.D. Bennett, and C.B. Andrews. 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site. *Groundwater*, Vol. 29, No. 6. 838-848.



**RESPONSE TO ADEQ COMMENTS DATED 16 MAY 2017 ON SITE ST012 CONTAMINANT MASS ESTIMATION PROCESS. LNAPL VOLUME CALCS; RECEIVED MARCH 23, 2017.
AN ADOBE.PDF OF AMEC FOSTER WHEELER (AMEC), ASSORTED LIGHT NON-AQUEOUS PHASE LIQUID (LNAPL) VOLUME CALCULATIONS; FROM VARIOUS TIME INTERVALS BETWEEN 2015 AND 2017**

It is ADEQ's opinion that contaminant mass can impact a remedy efficacy and that underestimating the contaminant mass can negatively impact a selected remedy. ADEQ suggests amec re-assess the contaminant mass; re-evaluate remedy options, as appropriate; collect additional data, as needed; and complete remedy pilot studies, as applicable, to bolster the proper remedy's success potential.

Response:

Contaminant mass estimates considered throughout the ST012 Comprehensive Environmental Response, Compensation, and Liability Act process have consistently included a conservative range in order to prevent underestimation that could impact the selected remedy. Remedial alternative evaluation in the Focused Feasibility Study (FFS) and remedy selection in the Record of Decision were based on contaminant mass ranges that exceed current estimates. The Remedial Design and Remedial Action Work Plan (RD/RAWP) and Addendum #2 both include step-wise evaluations and implementation of the remedy considering ongoing evaluations of remaining mass (including the Addendum #2 decision tree). Additional data collected over the last eighteen months has further defined remaining contaminant mass. For these reasons, the Air Force (AF) does not agree the suggested actions are necessary prior to enhanced bioremediation (EBR) implementation. The AF suggests that EBR remedy implementation proceed in order to make further progress in achieving ST012 remedial action objectives. Efficacy of the EBR technology at ST012 is best assessed by implementing the technology as indicated in the approved RD/RAWP and Addendum #2 and monitoring the EBR progress.

General Comments

1. A wider range of initial mass estimates should be employed in calculations and extend as high as 1,655,000 gallons. This wider range is justified by the strong dependence of the mass estimates on total soil porosity as described in the specific comments. Previous measures of total soil porosity at the site yield an average of 0.4, significantly higher than the assumed value of 0.3.

Response: See the discussion on porosity under response to specific comment 1 on the Pre-Steam Enhanced Extraction (SEE) Mass Worksheet.

2. Mistakes in the worksheets occur where estimated pre-SEE NAPL removal was subtracted from pre-SEE mass estimates calculated from TPH measurements. The mistake appears in the Worksheet "Pre-SEE mass" as described in the specific comments on this worksheet.

Response: *The calculation has been corrected (see response to Pre SEE Mass Worksheet specific comment 3), resulting in an approximately 4 percent increase to the Pre-SEE mass total.*

3. Calculation of remaining NAPL based on the subtraction of removed NAPL from initial NAPL is subject to the same variation as the initial estimate if post-SEE data are not collected from treated zones. Estimates of remaining NAPL should include field data collected post-SEE in the TTZ, TIZ and ROI. Assumed reductions of NAPL during SEE have no technical substantiation and appear to be arbitrary. The estimated total NAPL remaining post-SEE based on calculated saturations is 376,753 (95% reduction in TTZ) whereas the estimate based on literature saturations is 837,749 (70% reduction in TTZ). The difference in estimates is equal to the difference in estimates for the initial NAPL volume and valid justification is not provided for selecting one result over the other. Further, the persistence of NAPL appearance in former SEE process wells is not consistent with a 95% reduction in NAPL saturation.

Response: *The intent of evaluating different scenarios in the calculations (e.g., calculated saturations at 95 percent (%) reduction in the thermal treatment zone (TTZ) vs. literature saturations at 70% reduction in the TTZ) was to identify a range of possible conditions for consideration in the phase 1 EBR design. Ultimately, **selection** of a 'best fit' scenario as an initial design basis was the goal of the evaluation. In the Revised Draft Final Addendum 2, the scenario of 80% removal in the TTZs using the literature saturation values and applying the uncertainty factors was selected. Interpretation of monitoring data collected during EBR and future implementation of subsequent phases, if necessary, will address the uncertainty associated with this selection.*

4. Assumed reductions of benzene content in residual NAPL remaining post-SEE are not substantiated and appear to be arbitrary. The assumed reductions should not be employed to assess the mass of benzene remaining in post-SEE NAPL. The benzene mass in NAPL remaining in the TTZ, TIZ and ROI should be based on field data collected post-SEE including NAPL and groundwater analyses from the different treatment zones.

Response: *The quantitative values for assumed reductions of benzene content in the TTZ are supported by pre- and post- thermal enhanced extraction (TEE) data (see response to Post-SEE Mass Worksheet specific comment 7 for details). Therefore, additional data collection is not necessary and would only delay remedial **progress**. Collection of post-SEE data during EBR well installation and Additional Characterization was focused mainly outside of the technical impracticability zone (TIZ) where non-aqueous phase liquid (NAPL) benzene content reductions were not applied in the mass calculations.*

Specific Comments on the Worksheet entitled, "Pre-SEE mass"

1. As stated, "A porosity of 0.3 for all lithologic units was used to maintain consistency with the Terra Therm design assumptions."

No data or other basis was provided for assuming a total porosity of 0.3. Field data presented in Appendix B of the TEE *Pilot Test Work Plan* (BEM, 2007) includes 10 soil samples collected for physical analyses from four borings at various depths ranging from 150 to 242 feet below ground surface. The range of measured porosity values was 0.27 to 0.50 with an average of 0.40 and a median of 0.42. Assuming a porosity of 0.4 (rather than 0.3) lowers the calculated NAPL mass estimates based on measures of TPH and increases the NAPL mass estimate based on literature values provided in Step 4 on sheet 3 of 5 in Worksheet "Pre-SEE mass". For a porosity of 0.4, the pre-SEE mass estimates are 689,500 gallons (down from 804,500 gallons) for the calculated saturations and 1,655,000 gallons (up from 1,241,000 gallons) for literature saturation values. These example calculations demonstrate the strong dependence of the NAPL mass estimate on porosity, bring into question the assumed value of 0.3, and indicate a wider range of initial mass estimates should be employed in subsequent calculations. The lower range is provided by a porosity of 0.3 and the upper by 0.4.

Response: *The referenced porosity data was not found in Appendix B of the referenced report. The FFS provides a summary of porosity testing from studies previous to the TEE and suggests an average value for total porosity between 0.25 and 0.3 and an average value for effective porosity of 0.25. There is undoubtedly variation in porosity values across the different zones and with each of the geologic materials; however, the use of a porosity of 0.3 in the mass calculations is representative of overall average porosity and may be slightly conservative because it does not consider effective porosity, only total porosity. Even if total porosity on average is 0.4, use of 0.3 as effective porosity would be reasonable. Use of 0.4 effective porosity in the calculations is likely over conservative. For EBR planning and design purposes the 0.3 value is appropriate.*

2. Key points include, "Because LNAPL migration through the soil likely followed a tortuous path, an assumption of soil conditions being uniformly at residual saturation between known LNAPL-impacted locations may overestimate mass. To account for this potential an "uncertainty factor" was applied which provides a lower end estimate."

However, the LNAPL is also known to exist in pools within the saturated zone trapped beneath the interface of lesser permeable intervals overlying more permeable intervals (e.g., LPZ overlying the LSZ). Such pools are the likely source of persistent NAPL appearances in ST012-W11 and ST012-W37. An assumption of uniform residual saturation may underestimate this mass. To account for this potential an "uncertainty factor" should be applied which provides a higher end estimate and indicates a wider range of initial mass estimates should be employed in subsequent calculations

Additionally no technical or statistical basis was provided for assuming an "uncertainty factor" of 75% in the treatment volumes and 50% in EBR volumes.

The utilization of the "uncertainty factor" to lower the NAPL mass estimate was also illustrated to be unrealistic when compared to the NAPL mass removed during SEE as described in Step 7 of on page 6 of 7 in Worksheet "Post SEE mass".

Response: *The Uncertainty Factor was introduced to recognize the likelihood that the light non-aqueous phase liquid (LNAPL) did not uniformly migrate through and contaminate the porous space within soil in areas of LNAPL impact. Further technical or statistical basis for the quantitative values applied is not available. Areas of persistent LNAPL collection outside of the former SEE TTZs (i.e., unheated areas) may represent LNAPL pools. Because the phase 1 EBR implementation process begins with the removal of such LNAPL under pumping conditions, incorporation of this mass is not critical to EBR. A mobile LNAPL uncertainty factor may be considered in future mass calculation updates based on LNAPL data collected during initial pumping during EBR.*

3. Sheet 4 of 5 states, "NAPL removal is only applied to volumes using literature residual saturation because calculated residuals already account for NAPL removal via the average TPH values."

The calculations on Sheet 5 of 5 show the estimate of NAPL mass based on measured TPH soil concentrations includes the subtraction of 10,067 gallons from the UWBZ and 24,620 gallons from the LSZ that occurred before the TPH measurements. The volume calculations should be corrected as these subtractions incorrectly reduce the treatment zone mass estimates by 5% in the UWBZ and 10% in the LSZ.

Response: *The mass calculations have been corrected to remove the pre-SEE NAPL removals from the calculations for the calculated residual saturation.*

4. Sheet 5 of 5 Conclusion: "Using the literature values that BEM used in previous site modeling during the TEE pilot test and the new interpretations of LNAPL extent, the volume of LNAPL in the thermal treatment zones is estimated to be between 545,000 and 725,000 gallons, leaving between 240,000 and 480,000 gallons in the area outside the thermal treatment zones."

For reasons cited above, the range should be based on a range for the porosity. Based on porosity, the volume of LNAPL in the thermal treatment zones is estimated to be between 760,000 and 1,000,000 gallons, leaving between 480,000 and 650,000 gallons in the area outside.

Response: *See response to porosity Pre-SEE Mass Worksheet specific comment 1 above.*

5. Sheet 5 of 5 Conclusion: "Using the concentrations of TPH in the soil and the equation developed by Hawthorne and Kirkman, the amount of NAPL in the thermal treatment zone is estimated to be between 300,000 and 405,000 gallons, leaving between 185,000 and 365,000 gallons in the area outside the treatment zone."

For reasons cited above, the range should be based on a range for the porosity. Based on porosity variations, the volume of NAPL in the thermal treatment zone is estimated to be between 375,000 and 438,000 gallons, leaving between 314,000 and 367,000 gallons in the area outside the treatment zone.

Response: See response to porosity Pre-SEE Mass Worksheet specific comment 1 above.

Specific Comments on the Worksheet entitled, "Post-SEE mass"

6. Sheet 1 of 7 describes soil volumes with varying levels of NAPL removal during SEE in the CZ, UWBZ, LPZ, and LSZ. The soil volume in each vertical zone is divided into a TTZ (90%), surrounded by a TIZ (60%), that is surrounded by an ROI (30%) and finally remaining areas of no treatment by SEE.

The assumed reductions in each area and zone are arbitrary as no justification, case study, reference or other data were provided to support the assumptions. Therefore, these assumed reductions should not be employed to assess the mass remaining post-SEE. In particular, the assumption of a 30% reduction in NAPL mass in an unheated radius of influence (ROI) beyond the perimeter of extraction wells is inconsistent with site data and inconsistent with a Key Point in the Introduction Worksheet, *"Although some LNAPL was recovered prior to heating the subsurface, quantities were low and relatively unresponsive to water table depression caused by pumping initiated as part of the containment study."* The assumption implies that 30% of the initial NAPL could have been recovered with pumping alone.

Response: The intent of the TIZ and radius of influence (ROI) zones is to account for some removal of LNAPL beyond the TTZ. Temperature data beyond the TTZs shows some heat influence from SEE. Residual LNAPL became mobile in limited areas around the TTZs and was pulled to perimeter extraction wells during depressurization events. Monitoring during depressurization supports this interpretation. The estimated removals in the TIZ and ROI are intended to account for these removal mechanisms (i.e., not by pumping alone) with a decreasing removal percentage with increase in distance from the TIZ.

7. Sheet 1 of 7 describes the increase in temperature in the TTZ and TIZ as likely to cause a preferential volatilization of light VOCs including benzene. To account for this volatilization, volatilization reduction factors were applied to final mass estimates of NAPL in the TTZ (90%), the TIZ (25%), and elsewhere (0%).

The assumed volatilization reduction factors in each area are arbitrary as no operational data, case study, reference or other data were provided to support the assumptions. Therefore, these assumed reductions should not be employed to assess the mass of benzene remaining in post-SEE NAPL. Operational data from SEE may be available to assess a preferential removal of benzene compared to other NAPL components but an estimate for benzene mass removal based on extracted flow and measured benzene concentrations have not been provided. Is the 90% reduction in the TTZ based on

distillation, and if so, was the mass of steam injected sufficient to effect this reduction? Is the 25% reduction in the TIZ based on dissolution, and if so, was the flow of water through this zone sufficient to effect this reduction?

Response: *The contribution from LNAPL outside the SEE TTZs limits the usefulness of concentrations in extracted vapors and fluids for predicting changes in benzene content in residual LNAPL during SEE. However, the 90% assumed reduction in the TTZs is supported by NAPL composition data collected during the TEE Pilot Test where an 88% reduction in benzene content in the LNAPL was observed between pre- and post-TEE samples (see Table 6-1 of Kavanaugh et al, 2011). The SEE used more steam per volume treated than the TEE, therefore, similar or better reductions in benzene content in the residual LNAPL within the TTZ is justified. A lower value was applied in the TIZ to account for limited areas beyond the TTZ where boiling temperatures may have been achieved. The assumed reductions account for multiple potential removal mechanisms and not just distillation or dissolution.*

8. Sheet 2 of 7 states, "Contours were extended to include monitoring wells known to have observed LNAPL but lack additional evidence of LNAPL (e.g. boring logs not available)."

The figures accompanying the mass estimate worksheets do not show any contours in the LSZ extending out to LSZ-43 in contradiction to this statement. As a result, the volume of NAPL-impacted soil and NAPL volume that was untreated by SEE are underestimated.

Response: *At the time the LNAPL delineations and mass calculations were prepared, LNAPL had not been observed in LSZ43. The figures and statement were consistent at the time the calculations were prepared. Because of the complexity of the calculations, updates to the LNAPL delineations and mass estimates are performed when additional data from multiple sources is available. The delineation will be extended to LSZ43 in a future update.*

9. Step 6 on Sheet 4 of 7 includes a table with estimates of post-SEE residual NAPL.

No explanation was provided describing how the "Untreated EBR Volume" was calculated. The reported volumes suggest the volumes were simply the estimate of the initial volumes from Worksheet "Pre-SEE mass" less the revised estimated volumes of NAPL in the TTZ, TIZ and ROI presented in Step 4. If correct, do the estimates for the UWBZ and LSZ in the final column of Literature volume include the estimated NAPL in the "Mass Extent Attributed to Additional Characterization" shown in the accompanying figures? If this additional mass is not included, the Literature Volume (last column) in the LSZ for Untreated EBR should be about 500 gallons instead of 49,738 gallons.

The estimate for the remaining NAPL in the TTZ of the UWBZ using calculated saturations (first column) is 13,180 gallons incorrectly including NAPL removed before TPH measurements were made. The correct estimate appears to be 15,614 gallons.

The two groups of rows entitled, "Cobble Zone and Upper Water Bearing Zone Thermal Treatment Zone" and "Lower Saturated Zone Thermal Treatment Zone" have no explanation for how they were calculated or how they are used.

Response: *The Untreated EBR volume is the Pre-SEE total volume minus the Pre-SEE volume in the other three zones (TTZ, TIZ, and ROI). The additional characterization is not included in the calculation. The calculation of 49,738 gallons is correct.*

The comment on the 13,180 gallons is incorrectly attributed to the Upper Water Bearing Zone as this quantity is found in the LSZ. The comment is correct, the pre-SEE removal was included and should not be. The calculation has been corrected.

10. Step 7 on Sheet 6 of 7 provides a comparison of NAPL volume removed during SEE to calculated NAPL removal using assumed reduction factors and estimated initial NAPL volumes.

Model validity based on a "best fit" of calculated mass removed using an assumed reduction factor compared to the measured mass removed is flawed; the logic is circular. For example, using the literature calculated NAPL volume in the TTZ of the LSZ of 360,727 gallons and a reduction factor of 33% yields exactly the same NAPL removed as the TPH calculated NAPL volume with a reduction factor of 90%. Without substantiation, no valid reason exists to select one reduction factor over the other based on mass removed.

For the reason described above, the mass remaining in the TTZ, TIZ and ROI should be based on field data collected after completing SEE rather than unsubstantiated assumptions. The appearance and recovery of NAPL in former SEE process wells, including former steam injection wells, does not support a 90% reduction in NAPL volume if the initial, unheated NAPL volume was primarily residual. The volume of NAPL remaining in the TTZ, TIZ and ROI cannot be estimated with validity without the collection additional field data (soil sampling, groundwater sampling, etc.) consistent with the data collected to assess the initial NAPL volume.

Response: *The SEE design predicted 99% removal of volatile components within the TTZs based on the combined effects of LNAPL removal (~90% reduction) and benzene depletion in remaining LNAPL (~90% reduction). These values considered the TEE Pilot Test results and anticipated that the higher temperatures, longer durations, and pressure cycling achieved with the SEE would improve mass removals. Based on SEE data confirming design parameters were achieved and objectives were met, the predicted mass removal percentages were considered appropriate for use in the mass calculations. However, such calculations result in calculated mass removals that do not exactly match the actual mass removals. These calculations can be reconciled by adjusting the initial mass or by adjusting the mass removal percentages. Because several scenarios with different initial mass already exist within the calculations, it is logical to adjust the percent removals to calibrate to*

the actual mass removed. Therefore, calibrated scenarios were included in the Post-SEE Mass Worksheet that have lower percent removals for higher initial LNAPL mass in the evaluation. The initial mass scenarios selected for this calibration were scenarios that had predicted mass removals (using the initial 99% benzene removal assumption) that were relatively close to the actual mass removal. This approach is logical and not circular. Using the scenario with higher values of initial mass and lower percentage removal rates for the actual SEE mass removal (a 33% removal) as suggested in the comment uses a scenario that is inconsistent with the peak and significant decline in mass removal rate observed during SEE. This reasoning supports the validity of best fit evaluation.

Post-SEE data has been considered in LNAPL evaluations. Collection of additional post-SEE data is not necessary for implementation of Phase 1 EBR. Data collection during EBR will provide substantial data to refine the LNAPL distribution.

The amount of LNAPL removed from former SEE wells post-SEE is less than 1% of the mass removed during SEE. Transport of LNAPL from outside the TTZs and mobilization of NAPL that was formerly residual due to the continued elevated temperatures contribute to the presence of LNAPL inside the former TTZs.

11. Step 7 on Sheet 7 of 7 provides calculations of benzene mass in the remaining NAPL based on a uniform mass fraction of benzene in the pre-SEE NAPL and assumed reduction factors in benzene mass fraction in various treatment zones.

The assumed mass fraction of benzene in the pre-SEE NAPL appears to be uniform at 0.00356 although no value is provided in the Worksheet. A footnote states the value is based on LNAPL analysis during SEE, not before. Previous investigations at ST012 have analyzed NAPL samples for its makeup. These results are provided in Appendix L of the TEE Pilot Test Evaluation Report (2011) where the benzene mass fraction for modeling was reported to be 0.00222 in the UWBZ and 0.0083 in the LSZ. The UWBZ was unsaturated at the time of NAPL release and the residual NAPL in the UWBZ was weathered by natural volatilization and soil vapor extraction before becoming submerged. The result is a lower mass fraction of volatile compounds than found in the deeper LSZ NAPL that was weathered primarily by dissolution, a slower process. The benzene mass fractions cited in BEM (2011) for the separate zones is recommended over the single value of 0.00356.

As described in the comment above, the assumed volatilization reduction factors in each area are arbitrary as presented and should not be employed to assess the mass of benzene remaining in post-SEE NAPL. The benzene mass in NAPL remaining in the TTZ, TIZ and ROI should be based on field data collected post-SEE including NAPL and groundwater analyses from the different treatment zones.

Calculated benzene mass can be checked for consistency by comparison to GW concentrations. For the assumed mass fraction of 0.003556 in JP-4, the mole fraction of benzene is approximately 0.005 yielding an equilibrium groundwater concentration of 9

mg/L with the pre-SEE NAPL. A 90% reduction of mass fraction lowers the equilibrium groundwater concentration to about 0.9 mg/L. Hence, benzene concentrations in the former TTZ should not exceed 1 mg/L based on the Worksheet assumptions. These results also illustrate that a NAPL equilibrium concentration in groundwater will not approach MCL until the mass fraction is reduced by an additional two orders of magnitude.

Response: *The benzene fraction used in the mass estimate calculations is based on samples of extracted LNAPL during SEE (LNAPL which was mobilized during SEE) and did not change significantly during SEE. The value used represents an average since all three zones were contributing to the extraction. The average value used is consistent with the previous TEE results and is sufficient for identifying the approximate amount of benzene at the site.*

It appears that the benzene equilibrium concentrations calculated in the comment are based on benzene solubility at approximately 30 degrees Celsius. Current benzene concentrations in the former TTZs may be elevated beyond the calculated 0.9 milligrams per liter based on higher benzene solubility at elevated temperatures. Post-SEE groundwater samples collected have shown consistently higher benzene concentrations at or outside the former SEE TTZs than inside the former SEE TTZs which, although not able to confirm the 90% volatilization assumption, is consistent with the LNAPL benzene content being reduced within the former TTZs.

Compliance will be evaluated for the aquifer overall based on groundwater data collected at monitoring wells. It will be technically challenging to definitively sample localized groundwater in contact with residual LNAPL at equilibrium concentrations for groundwater. While calculation of such concentrations is valid for discussion, some degree of attenuation is likely between theoretical groundwater at equilibrium with NAPL in the soil and the measured exposure point concentration at a monitoring well.

12. The Conclusion states, "Contaminant mass remaining after SEE implementation was calculated. This method uses the final mass removed, as reported during TerraTherm weekly reports, to determine an adjusted percent removal by zone. Using the adjusted percent removal by zone, the remaining BTEX+N at the site is estimated to be between 134,000 and 194,000 pounds with a worst case scenario of up to 290,000 pounds."

As described in the comments above, these calculated masses of remaining BTEX+N are based on unsubstantiated assumptions for reduction. As demonstrated in the example calculation for the LSZ, any calculation of remaining NAPL based on the subtraction of NAPL removed from (widely varying estimates of) initial NAPL is subject to the same wide variation as the initial estimate. The most reliable method of assessing mass removed is the assessment of field data collected post-SEE.

Response: *Data collection during EBR will provide substantial data to evaluate distribution of residual and mobile fractions which will be utilized to improve the*

estimate of current mass remaining. Using pre-SEE data and assumptions on percentage mass removals provides a reasonable framework as it uses all available data on LNAPL distribution to estimate the quantity of LNAPL mass.

REFERENCES

Kavanaugh, Michael C., Deeb, Rula A., Nyman, Jennifer L., Stewart, Lloyd "Bo," D., and Widdowson, Mark A., 2011. *Final Report, Improved Field Evaluation of NAPL Dissolution and Source Longevity*. ESTCP Project ER-200833. October.